Microstructure and Abrasive Wear Properties of Chrome Alloy Steel

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***Abstract*—En 31 steel is widely used for applications like ball bearings and grinding media balls. The sliding wear properties of En 31 steel has been studied in the past, however the data on abrasive wear properties of En 31 steel is limited. En 31 steel was quenched and tempered at different tempering temperatures. Metallographic and hardness studies were carried out on heat treated samples. The hardened and tempered samples were tested using two body abrasive wear testing apparatus. The abrasive medium used in the present investigation was silicon carbide paper. The effect of normal load and sliding distance on wear loss of as received and heat treated specimens tempered at different tempering temperatures was investigated. The abrasive wear resistance of EN 31 steel with different hardness was compared under different test conditions. The worn out samples were observed by Scanning Electron Microscope to study morphology of worn surfaces. The abrasive wear resistance exhibited an increasing trend with increase in hardness and it was rationalized in terms of microstructure and the hardness.**

***Index Terms*—Steel, heat treatment, tempering, microstructure, hardness, abrasion**.

I. Introduction

The primary modes of wear responsible for degradation of the engineering components in industries are sliding wear, abrasive wear, erosive wear and chemically assisted wear. Abrasive wear accounts for more than 50 % failure of engineering components in industries. Several strategies can be used to enhance wear resistance of engineering components; use of alternative material, surface modification by application of wear resistant coatings and by altering microstructure and mechanical properties by way of heat treatment. Steels and cast irons are widely used for wear protection against hard particles. Apart from ceramic materials and cast irons, alloy steels have been used as grinding media for grinding and mixing of heavy and hard materials and also where high pressure and impact grinding or crushing methods are employed.The influence of abrasive particle properties such as size, shape and hardness has been investigated in the past. The abrasive wear behaviour of steels is well documented in the literature with respect to influence of abrasive particle properties, abrasive hardness and materials properties. [1-10].The abrasive wear behaviour of steels is also influenced by its microstructure. A limited amount of data is available on the effect of microstructure on abrasive wear properties of alloy steels. [6,-7, 11-15]. In the present work the effect of heat treatment on microstructure and abrasive wear properties of En 31 was investigated. The hardened specimens of En 31 steel were tempered at different tempering temperatures. The abrasive wear studies were carried using two body abrasion tester under different test conditions. The results of the investigation were rationalized on the basis of microstructural and hardness variation associated with tempering.

II. Experimental

A. Materials

The specimens used for the present study were in the form of a cylindrical bar of diameter 7 mm. The length of the specimen was 25 mm. The chemical composition of the material was obtained by wet chemical analysis method. The chemical analysis of as received sample conforms to EN 31 steel as given in Table 1.The specimens were subjected to heat treatment schedule as given in Table 2.

The bulk hardness of as received and heat treated specimens was measured using Rockwell hardness tester at a load of 150 kg. An average of five readings was reported in the result as shown in Table 3.

The specimens for the metallography were taken from the each category of the heat treated samples and as received samples. The specimens were ground and polished with successive emery paper 1/0, 2/0, 3/0, 4/0 followed by cloth polishing with alumina slurry. The polished specimens were etched with 2% Nital for observation of microstructure. The heat treated specimens were designated as A, B, C & D for specimens tempered at 100^0C, 400^0C, 460^0C, 560^0C temperatures respectively. The as received sample was designated as AR.

The micro structure of as received specimen AR is shown in Fig 1 (a) with pearlite and cementite phases.The micro structures of as hardened specimen, AH after water quenching is shown in Fig. 1(b) which reveals martensite, alloy carbides and some retained austenite. Fig. 1(c-f) shows the micro structure of specimens tempered at different tempering temperatures of 150^0C, 350^0C, 450^0C and 560^0C respectively. The microstructures show tempered martensite with alloy carbides, the morphology of martnesite becoming coarser with increasing tempering temperature.

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TABLE I. Chemical composition of en-31 steel

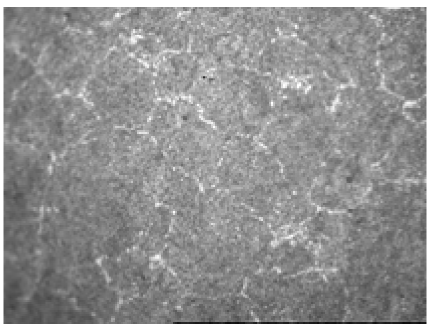
Element	C	Si	Mn	P	S	Cr
(Wt. %)	0.93	0.20	0.43	0.018	0.0047	1.43

Table II. Heat treatment schedule of en 31 steel

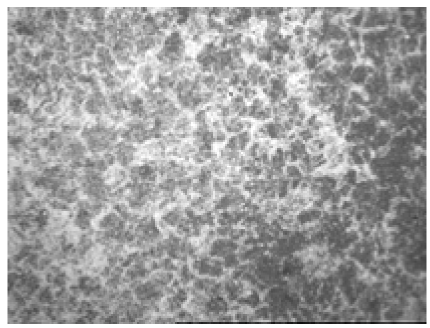
Step No.	Details of heat treatment
1	Heating to 500^0C (soaking time 30 minutes)
2	Austenitisation at 820^0C (Soaking time 30 minutes)
3	Water quenching and Tempering at 100^0C, 300^0C, 450^0C and 560^0C (soaking time 30 minutes)

TABLE III. Bulk hardness of as received and heat treated samples (hrc)

AR	A	B	C	D
22	52	44	36	31



(a)



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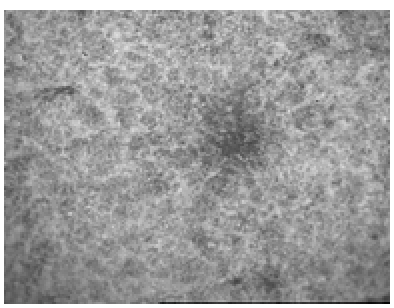

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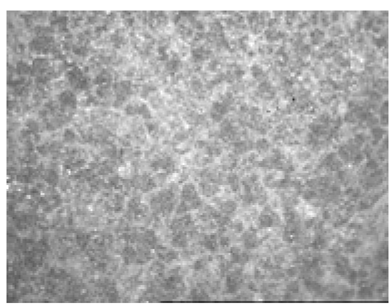

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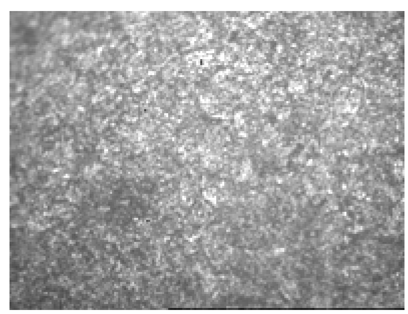
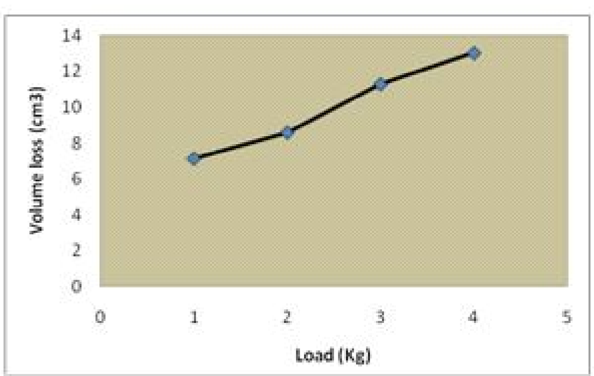
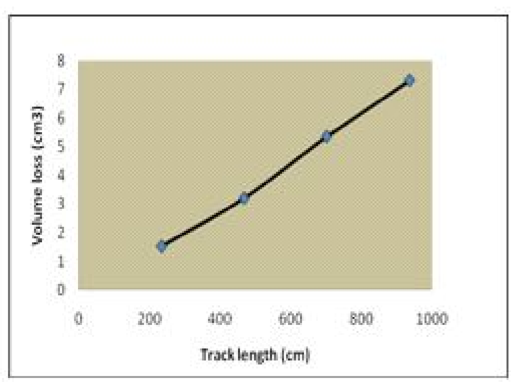


(e)

Figure 1. (a-e) Microstructures of En 31 steel (a) as received condition (b) hardened and tempered at 100^0C (c) Hardened and tempered at 350^0C (d) hardened and tempered at 450^0C (e) hardened and tempered at 560^0C. (Magnification 500 X)



(a)



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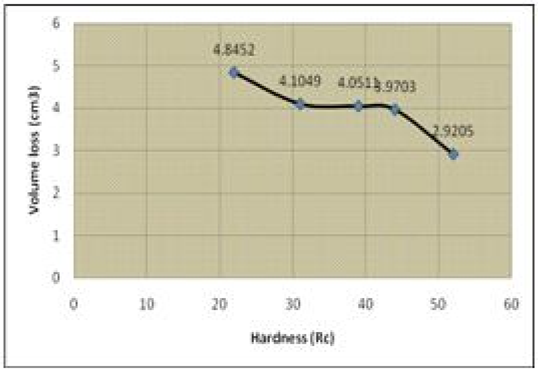

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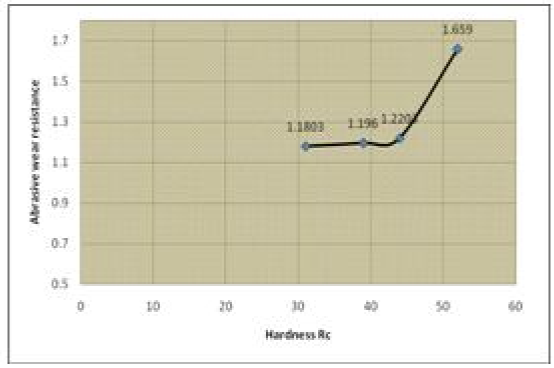
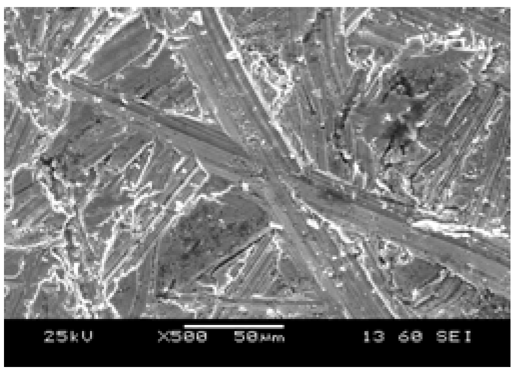


(d)

Figure 3. (a-d) (a) Effect of load on wear volume loss of AR specimen at a velocity of 1.2 cm/sec (b) Effect of track length wear volume loss of AR specimen at a load of 1 kg. and velocity of 1.2 cm/sec (c) Variation in volume loss of heat treated samples as a function of hardness of heat treated samples at a load of 4kg and velocity of 1.6cm/sec (d) Effect of hardness on abrasive wear resistance of heat treated specimens.



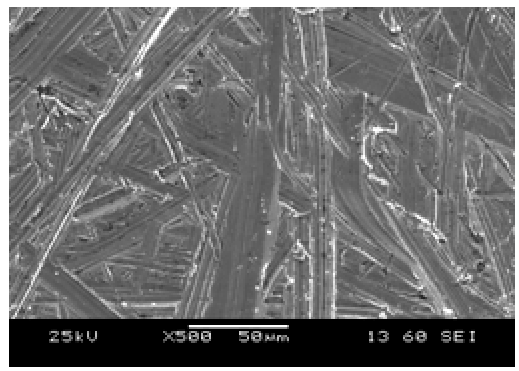


Figure 4. (a-b) (a) SEM image of AR specimen of EN 31 steel at load of 4 kg and velocity of 1.6 cm/sec (b) SEM image of specimen A of EN 31 steel at load of 4 kg and velocity of 1.6 cm/sec

B. Abrasive wear testing

The two body abrasive wear testing on En 31 steel specimens was performed using two body abrasion testing apparatus (DUCOM make). The specimens used for the test were in cylindrical form with diameter of 7 mm and height of 25 mm. The specimen under test is fixed in the specimen holder. The specimen rotates about its axis as it traverses on abrasive paper under the action of applied load. The lateral movement of the specimen after completion of one path ensures that specimen traverses fresh paper in every pass. The abrasive coated paper or cloth is held on a mild steel plate, which is firmly secured on machine bed.

A test load is applied on specimen pin with dead weight’s are placed above spindle to apply direct pressure on specimen pin. A photograph of the abrasion test apparatus is shown in Fig. 2. The specimens were polished up to 2/0 emery paper followed by cleaning with ethyl alchohol. After the test is over, the specimen is removed, cleaned and weighed on a digital electronic balance to an accuracy of 0.1 mg. The difference in initial and final weight was used to calculate mass loss. The abrasive tests were carried using silicon carbide abrasive paper (100 grit size) under different conditions.The effect of load on volume wear loss of as received specimen of EN 31 steel was studied at a velocity of 1.2 cm /sec and effect of track length on wear volume loss of En 31 steel was investigated at a load of 1 kg. The abrasive wear tests werealso performed on as received and heat treated specimens tempered at different tempering temperatures at a load of 4 kg and velocity of 1.6 cm/sec. In all the abrasion tests the RPM of specimen was kept constant at 50.

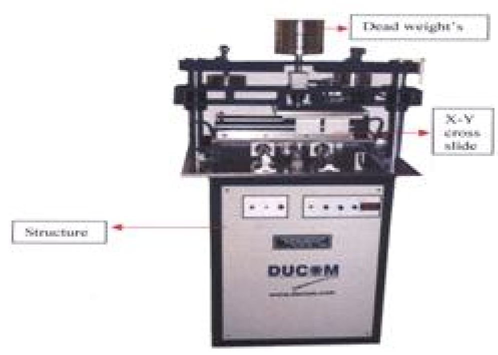


Figure 2. Photograph of Two body abrasion test apparatus

III. Results & Discussion

In the present investigation two body abrasive wear response of heat treated EN 31 steel was evaluated using two body abrasion test apparatus. Two different approaches were explored to assess two body abrasion behavior of EN 31 steel. The first approach was based on mass and volume

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loss measurements in two body abrasion test and second approach which was qualitative in nature, based on morphological studies of worn out surfaces.The volume wear loss of as received specimens of EN 31 steel exhibited linear relationship with operating parameters, i.e. normal load and track length, as shown in Fig 3. (a and b). With increase in load from 1 kg to 4 kg at velocity of 1.2cm/sec, the volume loss of as received specimen of EN 31 steel increased from 7.1332 cm^3 to 13.0283 cm^3. The increase in load is four times resulted in an increase in volume loss nearly by two times which can be attributed to increased depth of cut by abrasive particle on to the surface of steel. As seen from Fig. 3(b), with increase in track length, the volume loss has increased more or less linearly, obeying Archard's wear law [11].

Fig. 3(c) shows the effect of hardness of heat treated samples on abrasive wear volume loss at a load of 4kg and velocity 1.6cm/sec. It can be observed that the volume loss has decreased from 4.8452cm^3 to 3.9703cm^3, when the hardness is increased from 22 to 44 HRc. Thus an increase in hardness two times has decrease the volume loss by 1.2 times as compared to as received sample. The abrasive wear resistances of heat treated specimens were calculated by considering as received sample as reference. It can be seen from Fig. 3(d) that the specimen A with hardness of 52 is 1.659 times more abrasion resistant as compared to as received sample, which can be attributed relatively finer morphology of martensite and fine distribution of alloy carbides.

Samples B, C and D showed marginal increase in abrasion resistance of 1.2203, 1.1960 and 1.1803 times respectively.The morphology of abraded surface of as received and specimen A is shown in Fig. 4(a-b) which shows severely abraded surface of AR specimen; large and deep grooves can be observed on the surface. The material is removed by micro cutting process. In Fig. 4b, relatively shallow and finer grooves are observed resulting in less abrasion rate of specimen A with higher hardness and greater abrasion resistance which is also attributed to finer morphology of martensite and alloy carbides.

CONCLUSION

1) The hardened and tempered specimens of Cr alloy steel exhibited considerable difference in microstructure; finer morphology of martensite and alloys carbides was observed at lowest tempering temperature.
2) The bulk hardness of Cr alloy steel decreased with increase in tempering temperature.
3) The abrasive wear volume loss increased almost linearly with load and track length.
4) With increase in tempering temperature abrasive wear volume loss increased, although not proportionally.
5) The Cr alloy steel exhibited superior abrasion resistance atlowest tempering temperature which was attributed to the finer morphology of martensite alloy carbides.

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REFERENCES

[1] J. P. Blau, "*Friction, lubrication and wear technology*," ASM hand book, Vol 18. ASM international. The material information society; 1992.
[2] Zhenlin Lu, R. Qichang, Zhihao Jin, "An investigation of the corrosion abrasion behaviour 6% chromium cast steel", *J. Mater Process Technol*, vol. 95, pp. 180–184, 1999.
[3] J. Shu Sun,"The abrasion characteristics of some carbide containing alloys",in. Proc of the int. conf. on wear of materials, Ludema KC, editor, *ASME*, pp.79–86, 1983.
[4] He Lin, C. J. Zhang, "An investigation of the role of secondary carbides in martensitic steel during three body abrasion wear", *Wear* vol.16, pp.103–109, 1994.
[5] I. Sevim, I. B. Eryurek, "Effect of abrasive particle size on wear resistance in steels", *Mater. Des.* Vol. 27, pp. 173–81, 2006.
[6] Zum, K. H. Gahr, "Abrasive wear of two phase metallic materials with a coarse microstructure", in: Ludema KC, editor. Proc. of int. conf. on wear of materials, Vancouver, *ASME*, pp. 45–57, April 1985.
[7] O. P.Modi, P. Pandit, D. P. Mondal, B. K. Prasad, A. H. Yegneswaran, A. Chrysanthou, "High-stress abrasive wear response of 0.2% carbon dual phase steel: effects of microstructural features and experimental conditions", *Mater Sci Eng*, vol. 458, pp. 303–11, 2007,
[8] A. Misra, I. Finnie, "On the size effect in abrasive and erosive wear", *Wear*, vol. 65, pp.359–373,1981.
[9] L. Bourithisa, G. D. Papadimitrioua, J. Sideris, "Comparison of wear properties of tool steels AISI D2 and O1 with the same hardness", *Tribol Int*, vol. 39, pp. 479–89, 2006
[10] E. Badisch, Mitterer, "Abrasive wear of high speed steels influence of abrasive particles and primary carbides on wear resistance", *Tribol Int*, vol. 36, pp. 765–70, 2003.
[11] I. M. Hutchings, "*Tribology, friction and wear of engineering materials*", Edward Arnold, 1992.
[12] O. P. Modi, D. P. Mondal, B. K. Prasad, M. Singh, H. K. Khaira, "Abrasive wear behaviour of a high carbon steel: effects of microstructure and experimental parameters and correlation with mechanical properties" *Mater. Sci. Eng*, vol. 343, pp. 235–42, 2003.
[13] H. Saghafian, S. Kheirandish, "Correlating microstructural features with wear resistance of dual phase steel", *Mater. Lett.* vol. 61, pp. 3059–63, 2007.
[14] A. K. Jha, B. K. Prasad, O. P. Modi, S. Das, A. H. Yegneswaran, "Correlating microstructural features and mechanical properties with abrasion resistance of a high strength low alloy steel", *Wear*, vol. 54, pp. 120–128, 2003.
[15] S. G. Sapate, A. D. Chopde, P. M. Nimbalkar, "Effect of microstructure on slurry abrasion response of EN 31 steel", *Mat and des*, vol. 29, pp. 613–621, 2008.

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